USING GEOSPATIAL TECHNOLOGY TO ANALYSE VEGETATION VULNERABILITY: APPLICATION TO PRISHTINA, KOSOVO

***Albert BERILA*[1], *Florim ISUFI*[1*], *Ferat KRASNIQI*[1]**

DOI: 10.21163/GT_2025.202.06

ABSTRACT

The vulnerability of vegetation, influenced by factors of different levels, is a growing concern in Kosovo, particularly in the Municipality of Prishtina. This study investigates the extent and causes of vegetation vulnerability by analyzing key factors: roads, land use, slope, and settlements. Using GIS and Remote Sensing, the pairwise comparison method was applied to calculate the weight of each factor's impact. A weighted overlay method was employed to create a risk map of vegetation vulnerability. Results reveal that areas near roads, with gentle slopes, and unplanned land use are most vulnerable to vegetation degradation. Conversely, regions with steep slopes, planned land use, and distance from roads show lower vulnerability. Population density further exacerbates vegetation risk, emphasizing the need for proper planning and sustainable natural resource management. This research highlights the importance of positive land use practices and proactive measures to mitigate the adverse effects of rapid urbanization on natural vegetation.

Key-words: *Vegetation vulnerability; Geospatial Technology; Vegetation analysis; Factors weighting.*

1. INTRODUCTION

Contemporary lifestyle changes, coupled with the rapid and often uncontrolled expansion of settlements, have become increasingly prominent. Rapid population growth generates numerous challenges related to spatial organization and infrastructure development. Unplanned urbanization frequently results in critical issues, particularly where development occurs without prior planning, rendering the realization of comprehensive urban strategies virtually impossible. Consequently, this leads to multiple complications—both in the construction process and the management of built environments. Residential complexes are often constructed hastily, placing a high number of households within limited spatial confines. As a result, individuals experience a significant disconnection from the natural environment. The pace and scale of such urban development constitute a substantial burden on the population, frequently contributing to the onset of various health problems, including hypertension, neuroses, respiratory disorders, and arteriosclerosis. When these health issues are mapped spatially, it becomes evident that they are more prevalent in densely urbanized areas than in regions that maintain closer proximity to natural environments.

The natural world is shaped by a multitude of dynamic forces that act, to varying degrees, on vegetation. The cumulative effects of these forces—both natural and anthropogenic—constitute what is referred to as vegetation vulnerability. A wide array of factors contributes to vegetation degradation, including but not limited to human activities, armed conflict, both natural and deliberate fires, pests, natural disasters, and disease outbreaks (Tsegaye, 2019; Ganaie, Jamal & Ahmad, 2021; Badmaev & Bazarov, 2022; Maurya et al., 2020; Tsymbarovich et al., 2020). Among these, human activities have been identified as the most detrimental to vegetation health and sustainability (Badmaev & Bazarov, 2022; Maurya et al., 2020; Tsymbarovich et al., 2020; Minale & Gelaye, 2021). In this regard, people do a series of harmful actions that cause repairable damage (Nair & Tieguhong, 2021). Anthropogenic pressures—such as poor land management, expansion of road networks, proximity to settlements, and terrain accessibility—play a decisive role in the degradation of vegetation (Dien, 2004).

[1]*Department of Geography, Faculty of Mathematics and Natural Sciences, University of Prishtina, Prishtina, Republic of Kosovo, albert.berila@uni-pr.edu, florim.isufi@uni-pr.edu, ferat.krasniqi@uni-pr.edu*
[*]*Corresponding author*: florim.isufi@uni-pr.edu*

Consequently, areas that are remote or topographically inaccessible tend to be less exposed to human-induced threats. On the contrary, regions that are easily accessible are more susceptible to exploitation and ecological degradation (Minale & Gelaye, 2021). Furthermore, an increase in human population density and technological advancement correlates directly with environmental pressure and subsequent vegetation loss (EPA, 2021). The demand for agricultural land and forest products has further intensified the transformation of natural vegetation, often accelerated by technological innovations in agriculture.

Natural vegetation is essential not only for ecological stability but also for socio-economic wellbeing (Minale & Gelaye, 2021, Schröter et al., 2005). The connection of the earth's surface with the vegetation is extraordinary. Vegetation plays a vital role in reducing soil erosion and enhancing fertility by stabilizing soil surfaces (Minale & Gelaye, 2021; Sun, Hou & Chen, 2021; Berendse et al., 2015; Jin et al., 2021; Hou et al., 2020; North et al., 2021; El Kateb et al., 2013; Novara et al., 2018; Yu & Jia, 2014). Conversely, the absence or degradation of vegetative cover increases the risk of soil erosion and land degradation (Hou et al., 2020; Vieira et al., 2018; Moody & Martin, 2001; Morgan, 1986; Shakesby, Doerr & Walsh, 2000). In Kosovo, deforestation remains a principal driver of land degradation. A significant portion of the country's economy relies on agriculture, resulting in the conversion of vegetated lands into arable land. These transformations have led to significant alterations in vegetation cover over the decades. The degradation of natural vegetation in Kosovo poses a major threat to the sustainability of essential natural resources, such as water and soil (Wang & Stephenson, 2018; Wu et al., 2020; Huang, Van Den Dool & Georgakakos, 1996; Gebrehiwetk, 2004; Niu, Chen & Sun, 2015). Key contributors to vegetation degradation in Kosovo include rapid population growth, escalating demand for natural resources, illegal logging, and anthropogenic forest fires. Migration patterns, particularly from rural to urban areas in search of better livelihoods, have led to an intensification of construction, infrastructure development, and resource exploitation. These activities are particularly evident in Prishtina—the capital city—where post-conflict development has significantly impacted natural vegetation.

Although geoinformatics offers robust tools to assess vegetation vulnerability, their application remains underutilized, especially in Kosovo. Several studies have successfully employed geospatial technologies to analyze the impact of natural disasters on vegetation across the globe (Yin et al., 2020; Dashpurev et al., 2021; Gemitzi & Koutsias, 2021; Dutta et al., 2015; Gonçalves et al., 2015; Dindaroglu et al., 2021; Hislop et al., 2020). Due to human activities, the climate has changed, and such a change endangers the composition and distribution of vegetation by decreasing/destroying biodiversity and weakening the ecosystem (Bowler et al., 2020; Buizer, Humphreys & De Jong, 2014; Coomes et al., 2014; Hanewinkel et al., 2014; Khosravi et al., 2017; Lin, Xia & Wan, 2010; Lindner, 2010; Paterson & Newell, 2010; Ripple, 2013; Way & Oren, 2010; Wiens, 2011; Zhu et al., 2014). As a result of all this, the atmosphere will be threatened to cause the degradation of the living environment to increase—fragmentation and loss of vegetation (Buizer, Humphreys & De Jong, 2014; Awono et al., 2014; Evans, Murphy & De Jong, 2013; Hanski et al., 2015; Luttrell et al., 2014; Matthews, Cottee-Jones & Whittaker, 2014). Compared to traditional methods, the continuous monitoring of vegetated areas through the use of satellite data has tremendous advantages (Pei et al., 2018; Zhang et al., 2017). To analyze vegetative drought, one of the most widely applied indices is NDVI (Gomes, Bernardo & Alcântara, 2017; Kundu, Dwivedi & Dutta, 2016). Gomes, Bernardo and Alcântara (2017) identified that the areas with the highest level of vegetation change were those put under tremendous amount of stress. Such areas had high Land Surface Temperature (LST) values and low Vegetation Health Index (VHI) values. This work was carried out in southeastern Brazil for 14 years (2000-2014). Bhuiyan et al. (2017) for 29 years (1981-2010), examined the impact that thermal stress has on vegetation. The results clearly showed that heat stress damages vegetation to a great extent. Schröter et al. (2005) reported that the impacts of socio-economic activities on changes in vegetation distribution are evident. Berendse et al. (2015) concluded that the soil surface will be much more damaged if the vegetative cover layer is lost. Despite the global progress in geospatial vegetation studies, a significant gap remains in the scientific literature regarding the systematic mapping of vegetation vulnerability. A key limitation has been the lack of a coherent, standardized

methodological framework that can guide such research. Existing studies tend to focus primarily on identifying current vegetation status, underlying causes of degradation, and general ecological consequences. However, they often omit spatially explicit analyses that assess vulnerability and rank contributing factors according to their relative importance. This study aims to address these gaps by developing a detailed methodological workflow for mapping vegetation vulnerability using geospatial tools. The approach includes data acquisition (e.g., satellite imagery and elevation data) (**Tab. 1**), integration of environmental and socio-economic variables (slope, land use, proximity to roads and settlements), and the application of multi-criteria evaluation techniques, specifically the weighted linear combination method. The final output is a spatially explicit map of vegetation vulnerability, which can support both researchers and policymakers in environmental management efforts.

Although similar methodologies have been applied in other regions of the world, no such studies have been conducted in Kosovo. This absence is largely due to the lack of clear methodological standards. Therefore, this research not only fills a scientific gap but also proposes a replicable model for the application of geospatial technologies in vegetation vulnerability assessment.

In summary, the objectives of this study are threefold:

1. To design a replicable geospatial methodology for vegetation vulnerability mapping,
2. To identify and evaluate the key drivers of vegetation degradation in Prishtina, and
3. To generate a spatial vulnerability model that supports sustainable natural resource management.

This research is intended to serve as a reference point for future studies in the field of geoinformatics and environmental planning, contributing to more sustainable development practices in Kosovo and beyond.

2. STUDY AREA

Prishtina, the capital and largest city of the Republic of Kosovo, is situated in the northeastern region of the country, occupying a strategically significant position within the Balkan Peninsula (**Fig. 1**). The municipality is geographically bordered by Kastriot (Obiliq) to the west, Besiana (Podujeva) to the north, Graçanica and Lipjan to the south, Fushë Kosova to the southwest, Dardana (Kamenica) to the east, and Artana (Novobërdë) to the southeast.

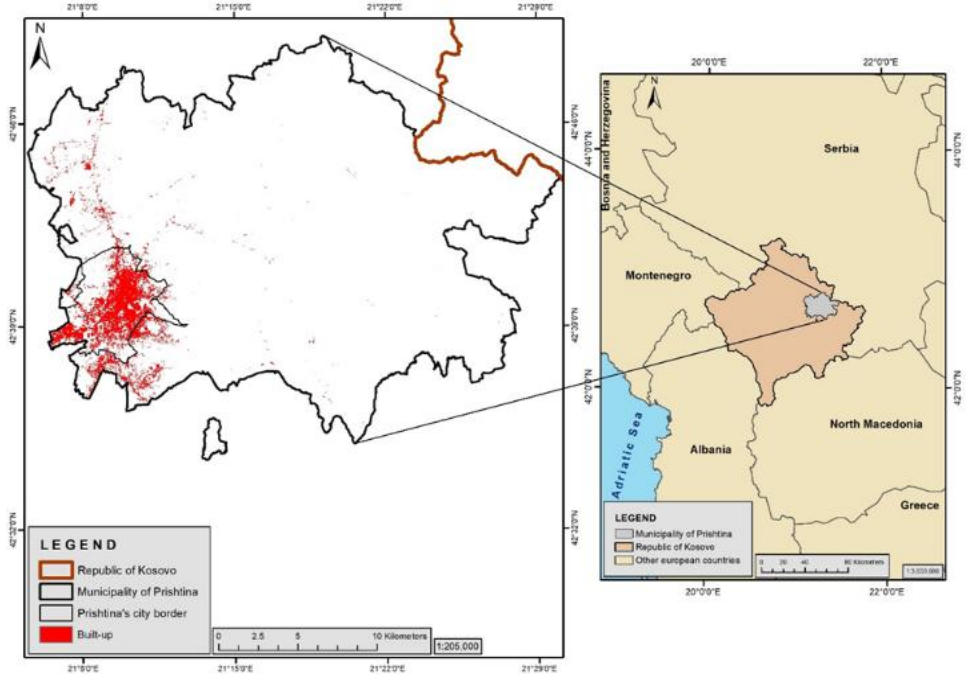

Fig. 1. Location of the study area (Berila & Dushi, 2021).

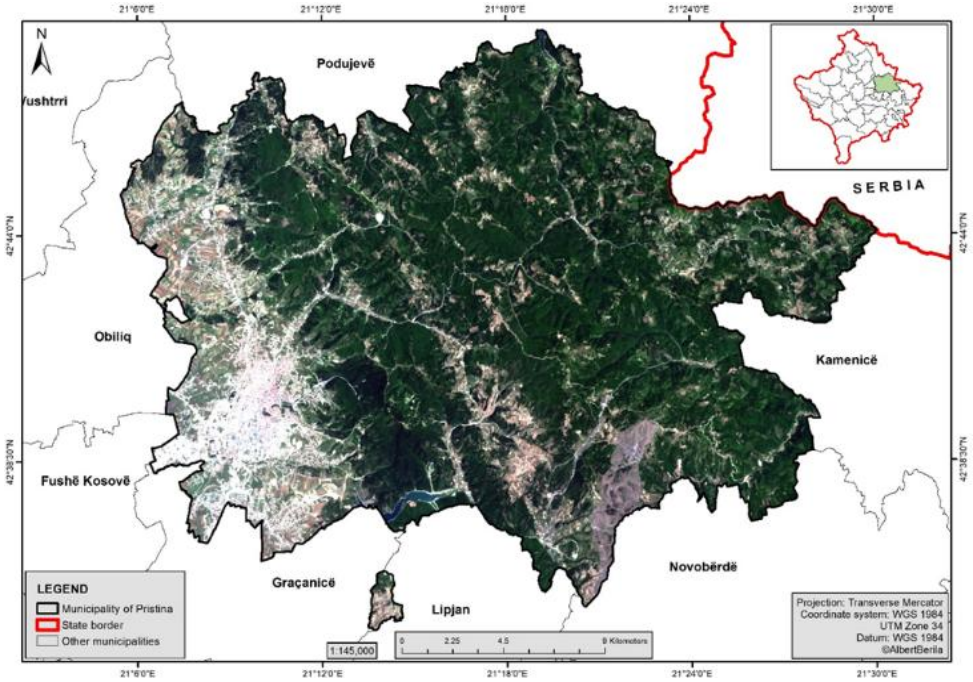

Fig. 2. Landsat 8 OLI RGB – composite (R = 0.6542 μm, G = 0.5609 μm, B = 0.4828 μm) of the study area (Berila & Isufi, 2021a).

Additionally, it shares a boundary with the Republic of Serbia along its northeastern frontier (**Fig. 2**) (Berila & Isufi, 2021a). The total area of the Municipality of Prishtina spans approximately 523 km². Geomorphologically, the municipality is part of the Kosovo Plain and is primarily composed of alluvial deposits originating from ancient lake sediments. Geologically, the region is characterized as a tectonic depression that formed during Oligo-Miocene tectonic activity, which has since shaped the contemporary landforms (Isufi & Berila, 2021; Berila & Isufi, 2021b; Municipality of Prishtina, 2021). The area experiences a continental climate, typified by cold winters and hot summers, with an average annual precipitation of approximately 600 mm (Isufi & Berila, 2021; Berila & Isufi, 2021b; Municipality of Prishtina, 2021).

Despite the global advancement in research on vegetation degradation and environmental vulnerability, Kosovo remains underrepresented in such investigations. The absence of localized studies is primarily due to a lack of clear, standardized scientific methodologies. Consequently, research in this domain has remained limited in scope and depth. To address this gap, there is a critical need for the application of advanced geospatial technologies—namely Geographic Information Systems (GIS) and Remote Sensing (RS)—which enable the integration and analysis of multiple environmental and anthropogenic variables (Minale & Gelaye, 2021).

In the context of Prishtina, the application of geospatial tools is particularly essential due to the rapid and unregulated environmental transformations observed in recent decades. These changes have largely been driven by the overexploitation of natural vegetation, primarily resulting from intensified human activities. Post-conflict urban expansion, infrastructure development, and the increasing demand for natural resources have significantly altered the landscape and degraded vegetative cover. To date, no comprehensive study has been conducted to evaluate the vulnerability of vegetation in this specific area using geospatial methodologies. Therefore, this research seeks to fill that gap by identifying the key environmental and anthropogenic drivers contributing to vegetation vulnerability and by producing detailed spatial maps that depict these patterns.

3. RESEARCH METHODOLOGY

The primary objective of this study is to assess the degree of vegetation degradation through the identification and spatial analysis of key contributing factors. To achieve this, we employed a multi-criteria geospatial approach that integrates several variables influencing vegetation vulnerability, as identified in relevant literature (Minale & Gelaye, 2021). Specifically, the following parameters were selected: slope, proximity to settlements, land use, and proximity to roads. Among these variables, terrain slope was considered particularly significant due to its direct influence on vegetation accessibility and susceptibility to human activities. To extract topographic information, we utilized a Digital Elevation Model (DEM) with a spatial resolution of 12.5 meters, obtained from the Alaska Satellite Facility (https://asf.alaska.edu/). This DEM was processed using ArcGIS 10.5, allowing for precise slope calculations at the cell level. The slope data were then classified into five distinct categories to reflect variations in terrain steepness across the study area (Berila & Dushi, 2021; Berila & Isufi, 2021c, 2021d).

The slope of the terrain is a significant factor influencing vegetation vulnerability, as steeper areas are generally less accessible and therefore less exposed to anthropogenic activities. Using ArcGIS 10.5, we derived the slope from the DEM through the ArcToolbox "Slope" function (**Fig. 3**). This output was then classified into five categories, each representing different degrees of slope steepness. This classification served as a basis for vulnerability analysis, with flatter areas typically indicating higher risk due to greater accessibility. The second variable analyzed was the proximity to roads. Road networks were manually digitized from existing maps of the study area using ArcGIS 10.5. Spatial analysis tools within the software were used to calculate Euclidean distances between vegetation and roads. These distances were categorized into four classes. Areas closer to roads were assigned lower values, indicating higher vegetation vulnerability, whereas areas further away were considered less vulnerable due to limited accessibility.

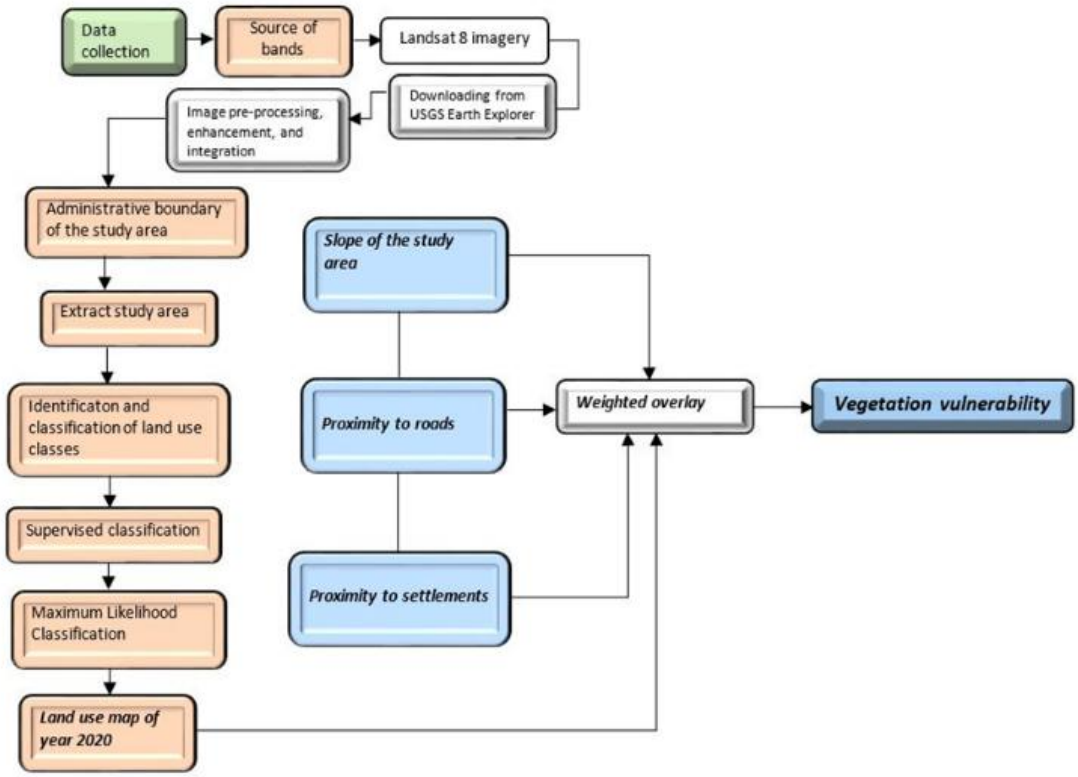

Fig. 3. Flowchart depicting methodology – general steps (compiled by authors).

To proceed further, it is necessary to scale the parameters that we will use, evenly (uniformly) according to Saaty (1987). To obtain the most accurate information on each option/variable, we had to know and consider the usefulness of each option or parameter entered so that, in the end, our decision-making was as rational as possible. For such a thing we have used multi-criteria evaluation using the weighted linear combination. For our study area, to determine the vulnerability of vegetation, we made comparisons of all variables included in the study, determining their importance according to our assessment. To have a clearer picture of the methodology used, we have presented such a thing in **Fig. 3**—general steps.

Table 1.

Data used in this study for compiling the land use map (compiled by authors).

Sensor type	Date	Path/Row	Cloud cover	Spatial resolution	Format	Source
Landsat 8 OLI	2020/09/06	185/30	0%	30m	Tiff	https://earthexplorer.usgs.gov/

Saaty (1987), in 1987, compiled a table called "The fundamental scale", in which are given a total of 9 points as a scale for assessing the importance of each variable under consideration—this is presented in **Tab. 2**. In the Analytic Hierarchical Process (AHP), we used the scale given by Saaty (Saaty, 1987) (**Tab. 3**). Through this scale, we have determined the values which we have compared for each variable considered.

Table 2.

Saaty's scale – the fundamental scale (Saaty, 1987).

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Exteme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to spam the matrix

For each pair, the weight was categorized—according to the importance of participating in the process—each of them was compared and, finally, they were recorded in a pairwise comparison matrix (Minale & Gelaye, 2021) (**Tab. 4**). The following constraint is met by a_{ji} and a_{ij} (Minale & Gelaye, 2021):

$$a_{ji} \times a_{ij} = 1 \quad (1)$$

in column j of the matrix, the element of row i, is a_{ij} (Minale & Gelaye, 2021).

Following the establishment of weights, each factor layer was reclassified and integrated using the Weighted Linear Combination (WLC) method within ArcGIS. In this overlay process, each raster cell's value was multiplied by the corresponding weight of its parameter. The final vegetation vulnerability model was produced by summing the weighted values of all cells. Higher cumulative values represent areas with greater susceptibility to degradation, while lower values indicate areas of relative ecological stability.

The overall methodological framework—illustrated in **Fig. 3**—ensures an objective and replicable approach to vegetation vulnerability assessment. By combining environmental and anthropogenic indicators within a geospatial context, this method supports the development of informed, spatially targeted conservation and land management strategies.

Table 3.

Saaty's scale – the fundamental scale (Saaty, 1987).

Scale	Definition	
9	Extremely	More important
7	Very strong	
5	Strong	
3	Moderately	
1	Equally important	
1/3	Moderately	
1/5	Strong	
1/7	Very strong	Less important
1/9	Extremely	

Table 4.

Saaty's scale – the fundamental scale (Saaty, 1987).

Factors	S	Pr	Ps	Lua	Weight
Slope (S)	1	1/2	1/2	5	0.24
Proximity to road (Pr)	2	1	2	3	0.40
Proximity to settlement (Ps)	2	1/2	1	3	0.28
Land use administration (Lua)	1/5	1/3	1/3	1	0.08

4. RESULTS AND DISCUSSIONS

4.1. Slope

The spatial distribution of vegetation is historically shaped by ecological conditions, natural evolution, and anthropogenic pressures. Among the primary physical factors influencing vegetation structure and vulnerability is terrain slope. Topography not only guides ecological processes but also exerts socio-economic implications, determining the suitability of land for settlement, agriculture, and infrastructure. Sloped terrains enhance erosion processes and constrain human activities, whereas flat lands are more accessible, favoring development and intensive land use.

Globally, more than 90% of the population resides in areas below 400 meters above sea level, typically lowland zones where economic activities are most intensive. These areas are preferred for mechanized agriculture, urban expansion, and infrastructure development. Human modification of natural landscapes—driven by technological advancement and socio-economic needs—intensifies degradation. Flattened areas with high accessibility are particularly vulnerable to these modifications, while steep and elevated regions remain more preserved.

Topographic characteristics, particularly terrain slope, play a fundamental role in shaping the spatial distribution, density, and structure of vegetation. The slope of the land not only influences ecological processes but also governs the extent to which an area is accessible and suitable for human activities.

Numerous studies have demonstrated a strong correlation between slope gradients and vegetation patterns, affirming that steeper terrains tend to preserve their natural cover due to reduced human interference (Giroux, Bergeron & Veillette, 2001; Lin et al., 2014; Simard et al., 2007; Wang et al., 2014). Furthermore, slope and altitude are known to affect forest diversity, contributing to variations in vegetative composition and ecosystem resilience (Fu et al., 2004). In the context of the Municipality of Prishtina, our slope analysis—derived from a 12.5-meter resolution Digital Elevation Model (DEM) obtained from the Alaska Satellite Facility—reveals a distinct spatial pattern. The eastern, northeastern, and southeastern regions exhibit higher slope values, whereas the western areas are predominantly flat.

This topographic configuration has direct implications for land use. Flat terrains, due to their accessibility and suitability for agricultural activities, are more prone to urban expansion and infrastructure development. Consequently, these areas are at a higher risk of vegetation degradation. The slope values within the study area range from 0 degrees (indicating flat land) to a maximum of 47 degrees (**Fig. 4**). Areas characterized by higher slope values are generally less affected by anthropogenic pressures, as the steepness poses significant challenges for construction, mechanized farming, and other land-altering activities. This natural inaccessibility serves as a protective factor, preserving vegetation and reducing ecological disturbance.

Given the critical role of terrain slope in shaping vegetation vulnerability, its inclusion as a core variable in this study was essential. However, it is important to acknowledge a methodological limitation: the use of a DEM with a 12.5-meter resolution, while adequate for regional-scale assessments, may not capture micro-topographic variations. Future studies are encouraged to utilize higher-resolution DEMs to enhance spatial precision and improve the granularity of terrain analysis. Terrain slope emerges as a key determinant of vegetation vulnerability. Steeper areas remain relatively intact due to natural constraints, while flat, low-lying areas are increasingly exposed to anthropogenic threats. These findings underscore the importance of integrating topographic variables into environmental planning and land-use decision-making processes.

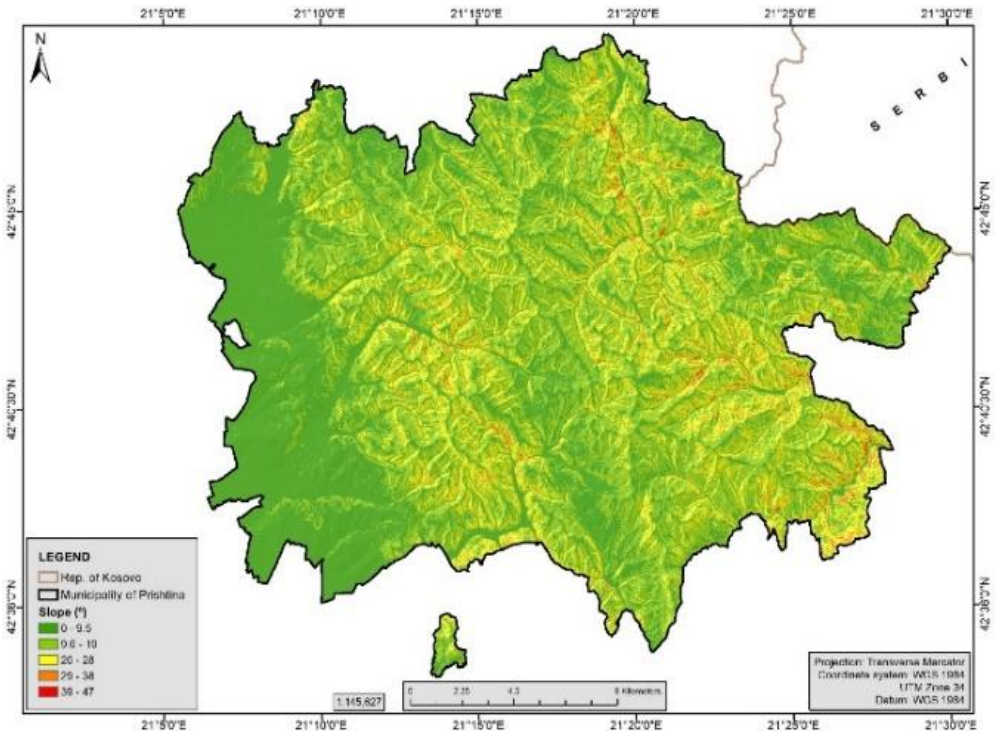

Fig. 4. Slope of the study area (compiled by authors).

4.2. Nearness to road

Road networks are among the most influential anthropogenic factors driving landscape transformation and vegetation degradation. As populations grow and economic activities expand, the demand for connectivity and mobility increases. Roads enable the movement of goods and people, but they also serve as vectors for ecological disturbance, facilitating access to previously undisturbed areas and accelerating processes such as deforestation, habitat fragmentation, and soil erosion.

The impact of roads on vegetation extends beyond the physical footprint of the infrastructure itself. Although roads occupy a relatively small proportion of land surface, their influence radiates into the surrounding environment. A variety of associated activities—such as increased vehicular traffic, emission of pollutants, noise, dust deposition, and land compaction—collectively contribute to the degradation of vegetation in adjacent areas. Numerous studies have documented the adverse ecological effects of roads, noting significant changes in vegetation composition and structure near road corridors (Findlay & Bourdages, 2000; Shakesby, Doerr & Walsh, 2000).

Vegetation located in close proximity to roads is particularly vulnerable due to its increased exposure to anthropogenic disturbances. In contrast, areas that are difficult to access due to the absence of road infrastructure tend to remain relatively intact, protected by natural barriers such as terrain slope, elevation, and remoteness. For this reason, proximity to roads was selected as a key variable in our study to assess vegetation vulnerability. Using ArcGIS 10.5, we digitized all road segments within the study area as line features and conducted a proximity analysis. The distances from roads to vegetated areas were categorized into eight distance intervals, ranging from 0 km (indicating immediate adjacency) to 4.8 km (**Fig. 5**). The spatial pattern of road density in Prishtina reveals a concentration of roads in the western region of the municipality, which also corresponds to zones of higher urbanization.

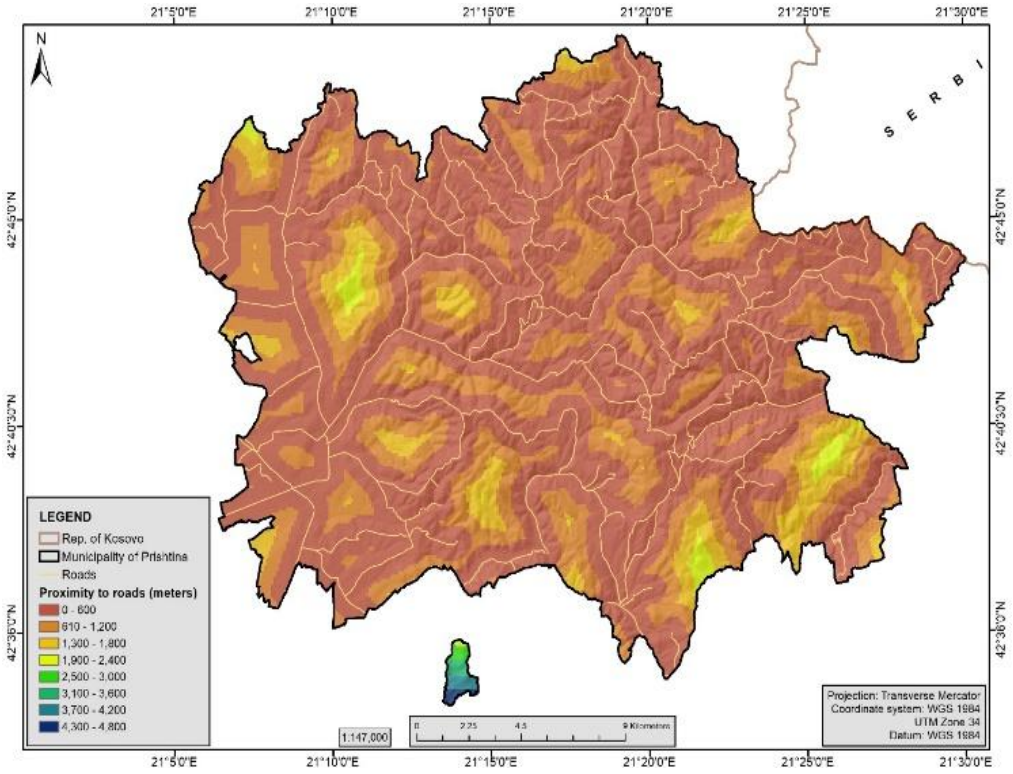

Fig. 5. Proximity to roads of the study area (compiled by authors).

This spatial correlation confirms that human activities are more intense in areas with greater road accessibility. In pursuit of minimal costs and maximum utility, individuals and communities tend to settle near roads, thereby increasing the likelihood of land conversion for agriculture, infrastructure, housing, and other uses. Consequently, vegetation near roads is subjected to heightened levels of disturbance through deforestation, logging, soil cultivation, and the expansion of the built environment. The general pattern indicates that the greater the accessibility, the higher the level of vegetation vulnerability—and vice versa.

While the methodology employed effectively illustrates the relationship between road proximity and vegetation degradation, certain limitations must be acknowledged. The accuracy of road digitization could have been improved through the use of high-resolution topographic maps or official road network datasets. The reliance on general base maps may reduce spatial precision. Moreover, the high density of road features can lead to cartographic clutter, complicating the process of spatial analysis. Future studies should consider using more detailed geospatial data and carefully manage map symbology to avoid overlapping features and visual confusion.

4.3. Proximity to settlements

Human settlements have historically evolved from rudimentary structures into complex urban systems, significantly reshaping natural landscapes and exerting continuous ecological pressure. The unregulated expansion of settlements and inefficient land use have contributed to the transformation of fertile agricultural areas and native vegetation into built-up environments, particularly in rapidly urbanizing regions.

The proximity of vegetation to human settlements is a critical factor influencing its vulnerability. Areas situated near settlements are frequently exploited for various socio-economic purposes, including the extraction of energy resources, construction materials, agricultural expansion, and other development-driven activities. For this reason, settlement proximity was included as a key variable in assessing vegetation vulnerability in this study. As noted by Dien (2004), the presence and expansion of settlements have a particularly strong and often detrimental impact on vegetation, especially in peri-urban zones.

Vegetation near settlements is more susceptible to degradation due to intensive land-use pressures, while areas located further from populated zones—particularly those that are difficult to access—tend to remain better preserved. To analyze this relationship, we employed ArcGIS 10.5, utilizing the Euclidean Distance tool from the Spatial Analyst toolbox to calculate the linear distance between vegetated areas and the nearest settlements. The resulting proximity values in the study area range from 0 km (immediate adjacency) to 6.3 km (maximum distance), as illustrated in **Fig. 6**.

The spatial distribution of settlements in Prishtina reveals a notable concentration in the western part of the municipality. This area, characterized by a higher density of built-up zones, also exhibits more significant vegetation degradation. The analysis confirms a direct correlation between settlement density and vegetation vulnerability: as settlement presence increases, so does the pressure on adjacent vegetated areas. This relationship underscores the impact of urban sprawl on the ecological stability of the region.

Settlements were digitized as point features using existing base maps of the study area. While this method proved effective for general proximity analysis, a limitation of the study lies in the absence of higher-resolution topographic maps, which could have improved the accuracy of settlement delineation. Overlapping features and excessive point density may also create visual clutter in cartographic outputs and analytical challenges in spatial modeling.

To enhance future research, it is recommended to utilize higher-scale and more detailed topographic or cadastral datasets, which allow for more precise settlement mapping. Additionally, selecting study areas with manageable settlement density can reduce spatial complexity and improve the clarity of vulnerability assessments.

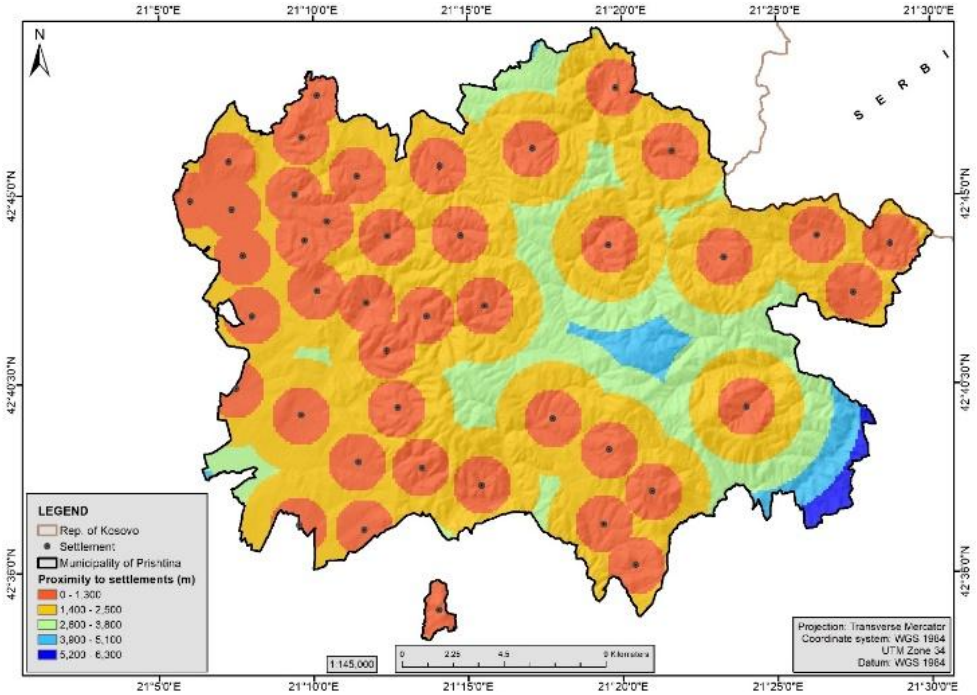

Fig. 6. Proximity to roads of the study area (compiled by authors).

4.4. Administration of the land

Land is a finite and multifunctional resource that plays a central role in sustaining ecological balance, supporting biodiversity, and enabling economic productivity. The manner in which land is utilized—and more importantly, how it is administered—has a direct and significant impact on the integrity of surrounding ecosystems, particularly vegetation. Poor land administration, characterized by unregulated urban sprawl, unsustainable agricultural expansion, and lack of environmental oversight, is one of the principal drivers of vegetation degradation and land cover transformation.

Effective land management is critical for maintaining the resilience of vegetated areas. Where land use is guided by sustainable planning and regulatory frameworks, vegetation is better preserved. Conversely, poorly managed land often experiences accelerated degradation. Land management practices are influenced by a wide array of local and global factors, including socio-economic development, governance, environmental policies, and population pressures (Minale & Gelaye, 2021; Pfaff et al., 2007).

In this study, land use within the Municipality of Prishtina was categorized into five major classes based on the type, intensity, and spatial distribution of land cover (**Fig. 7**). These classes were subsequently reclassified to reflect varying degrees of vegetation vulnerability. The analysis reveals that Prishtina has experienced substantial land mismanagement, particularly following the 1999 conflict. The rapid and often unregulated migration to the capital city has intensified land consumption without adherence to planning standards (Isufi & Berila, 2021). Large areas of vegetation have been cleared to accommodate residential developments, transportation infrastructure, and expanded agricultural fields. The phenomenon of deforestation, combined with poorly enforced environmental policies, has further exacerbated the situation.

As illustrated in **Fig. 7**, the western part of the municipality is almost entirely occupied by built-up areas and, in some zones, agricultural land. The dense settlement pattern and the rising demand for land resources in this region suggest that vegetation degradation is both ongoing and intensifying. The results of this study, supported by empirical evidence and existing literature, clearly indicate that poor land administration is a major contributor to environmental vulnerability in Prishtina.

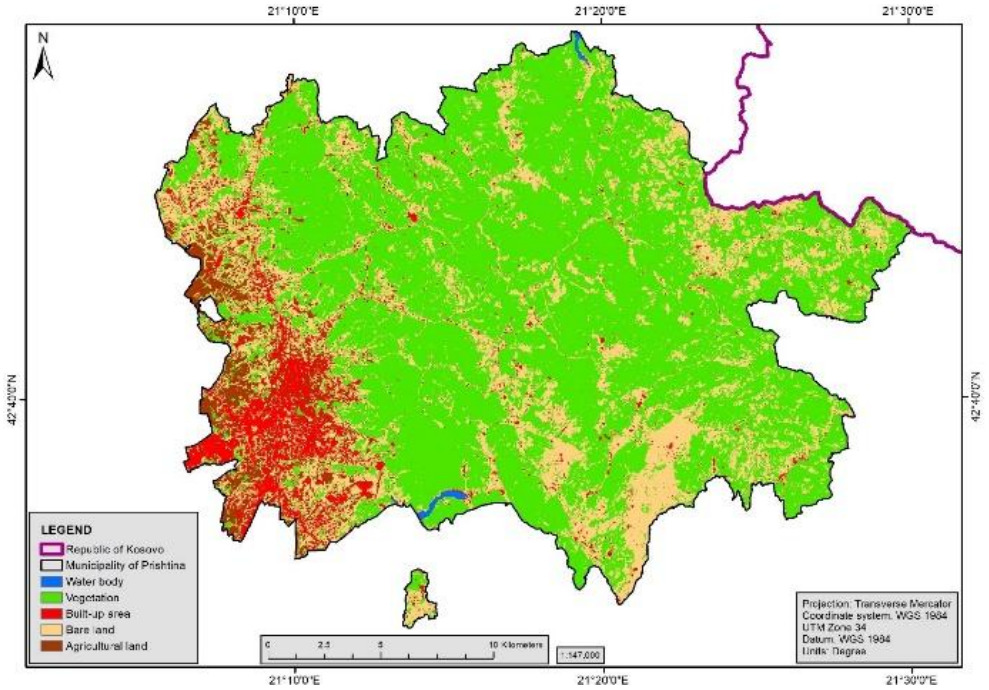

Fig. 7. Land use administration of the study area (compiled by authors).

The final variable analyzed in this study was land use, derived from a 2020 satellite image obtained from Landsat 8, accessed through the official United States Geological Survey (USGS) platform. The classification of land use plays a fundamental role in identifying high-risk zones for vegetation loss. However, the use of a 30-meter spatial resolution image imposes certain limitations on the granularity and precision of the analysis. In particular, pixel-based classification at this resolution may not accurately capture small-scale variations in land use, which are critical for fine-tuned environmental assessment. To enhance the reliability and accuracy of future research, it is recommended that satellite images with higher spatial resolution be employed. High-quality imagery allows for more precise delineation of land cover classes and supports more detailed monitoring of land use changes. Special attention should also be paid to pixel clarity and spectral definition during image processing to minimize classification errors and improve interpretability.

4.5. Compilation of the vegetation vulnerability map

Vegetation regeneration is most likely to occur in areas with limited human access—typically regions distant from roads and settlements. Consequently, dense vegetation is predominantly found in remote and topographically challenging areas, while vegetation in flat, accessible regions faces greater degradation. However, with the accelerated pace of global development and the expansion of infrastructure networks, such undisturbed areas have become increasingly rare. Modern transportation systems have drastically reduced the isolation of once-remote landscapes, increasing anthropogenic pressures even in previously inaccessible zones.

This pattern is also evident when analyzing altitudinal variations. Vegetation in elevated terrains and steeper slopes is generally less disturbed due to limited agricultural viability, erosion risks, and construction challenges. Conversely, flat and low-lying areas are often targeted for urban expansion, agriculture, and infrastructure development, making them more susceptible to vegetation loss.

In the context of the Prishtina municipality, four vegetation vulnerability classes were delineated using geospatial analysis tools (**Fig. 8**). These classes reflect varying levels of risk based on a combination of environmental and anthropogenic variables.

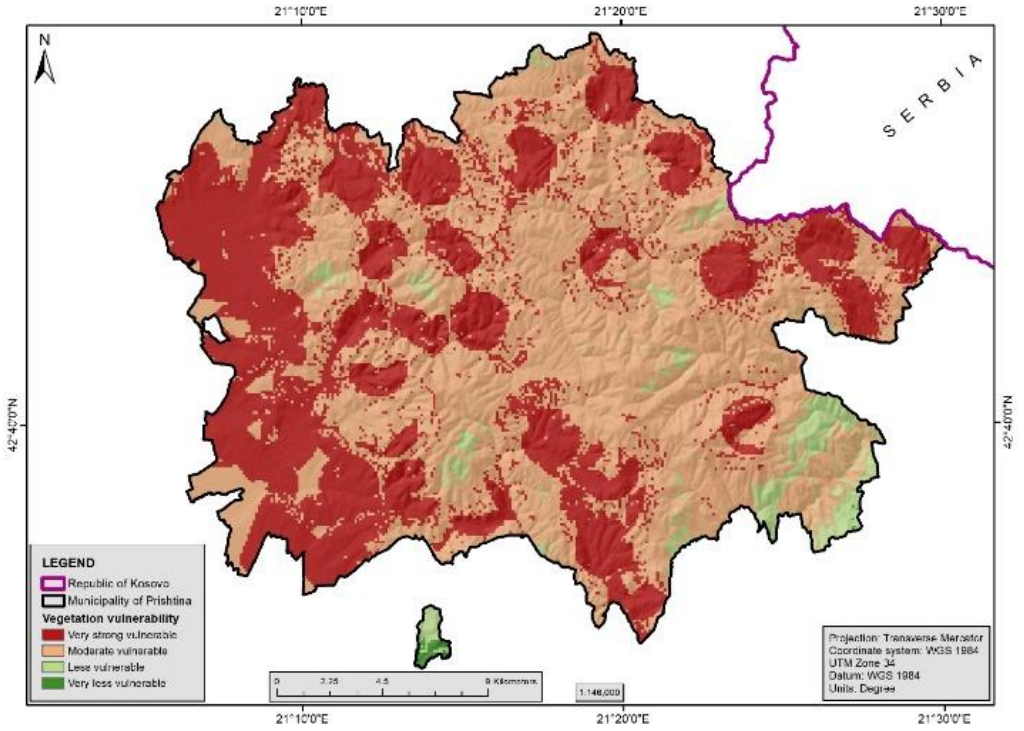

Fig. 8. Vegetation vulnerability map of the study area (compiled by authors).

Areas identified as highly vulnerable are predominantly located in flat terrains, near dense settlement clusters, and adjacent to road networks. In contrast, zones exhibiting lower vulnerability are situated on steeper slopes, at greater distances from built environments, and in regions where land use is managed more sustainably.

Our findings indicate that vegetation in Prishtina is under increasing threat, primarily due to population growth and the associated rise in demand for housing, energy, and agricultural land. The northeastern portion of the municipality, along with scattered patches across and a notable area in the south, were identified as the least vulnerable. These zones benefit from natural barriers and/or better land administration practices, which mitigate direct human impact.

A particularly noteworthy observation is the significant role of terrain slope in buffering against vegetation degradation. Steeper terrains are not only less accessible but also less suitable for cultivation due to poor soil fertility and high erosion potential. As a result, such areas tend to preserve their vegetative cover more effectively. Conversely, forested zones located near road infrastructure are highly susceptible to deforestation, emphasizing the compounded effect of accessibility and economic exploitation. The compiled vegetation vulnerability map thus serves as a critical spatial tool for environmental planning, enabling policymakers and land managers to prioritize conservation efforts in the most threatened areas while reinforcing protective strategies in ecologically stable zones.

5. CONCLUSIONS

Assessing vegetation vulnerability is critical for ensuring sustainable land use and for implementing targeted environmental protection strategies. Vegetation serves as a vital ecological component, regulating climate, supporting biodiversity, and maintaining soil quality. In this context, the present study offers a detailed spatial analysis of vegetation vulnerability within the Municipality of Prishtina, emphasizing the need for integrative geospatial approaches in understanding landscape dynamics and environmental degradation.

The findings of the study reveal that Prishtina, although rich in vegetative cover, faces serious degradation risks. Uncontrolled expansion of settlements, intensification of agriculture, and continuous development of road networks are key drivers of vulnerability. Our results confirm that vegetation is most threatened in areas with flat terrain, which are highly suitable for cultivation and construction due to their gentle slope and accessibility. Conversely, regions with steeper slopes demonstrate reduced vulnerability, as their topographic complexity limits human interference and discourages intensive land use.

The role of terrain slope is particularly significant: areas with low slope values are under greater pressure due to their agricultural potential and ease of access, while steeper terrains, often prone to erosion and less fertile, tend to remain less exploited. Similarly, proximity to roads and settlements emerged as strong determinants of vegetation degradation. Vegetation located near road infrastructure or within rapidly urbanizing zones faces increased risks due to human encroachment, pollution, and fragmentation of natural habitats.

Furthermore, poor land administration practices in Prishtina have exacerbated the situation. The post-war period has witnessed an accelerated transformation of vegetated land into urban and agricultural areas, often without adherence to sustainable planning or environmental regulation. Areas with effective land governance and environmental oversight exhibit better preservation of vegetation, underscoring the importance of institutional capacity and regulatory frameworks in conservation efforts.

This research provides a scientifically grounded vegetation vulnerability map that categorizes areas into four distinct risk levels, enabling policymakers, urban planners, and environmental managers to identify priority zones for conservation and rehabilitation. The methodology employed—based on the integration of GIS, Remote Sensing, and multi-criteria evaluation via the Analytic Hierarchy Process (AHP)—demonstrates the robustness and replicability of geospatial tools in environmental analysis. While limitations exist due to the moderate spatial resolution of the DEM and satellite imagery used, the study presents a strong foundation for future work that can incorporate finer-resolution data and temporal dynamics.

An equally important contribution of this study lies in addressing the existing gap in the literature regarding geospatial analyses of vegetation vulnerability. The methodological framework proposed here can serve as a template for similar studies in other regions facing comparable environmental pressures. By detailing every step—from data collection and factor weighting to spatial modeling and vulnerability mapping—this study encourages the adoption of best practices and fosters interdisciplinary research across geography, environmental science, and spatial planning.

Ultimately, this study reinforces the indispensable role of geospatial technology in assessing environmental vulnerability and guiding sustainable development. It urges decision-makers in Prishtina and beyond to prioritize the integration of spatial data and environmental intelligence into land use policy. Moreover, it calls on researchers to further explore and refine geospatial methods, ensuring their broader application in regional and global environmental assessments.

The degradation of vegetation is not only an ecological concern but a socio-economic challenge that requires coordinated efforts, informed by scientific data and implemented through evidence-based policies. This research contributes meaningfully to that endeavor by offering both a diagnostic tool and a roadmap for sustainable landscape management.

REFERENCES

Awono, A., Somorin, O. A., Eba'a Atyi, R., Levang, P. (2014). Tenure and participation in local REDD+ projects: Insights from southern Cameroon. *Environmental Science & Policy*, *35*, 76-86. https://doi.org/10.1016/j.envsci.2013.01.017

Badmaev, N., Bazarov, A. (2020). Correlation analysis of terrestrial and satellite meteodata in the territory of the Republic of Buryatia (Eastern Siberia, Russian Federation) with forest fire statistics. *Agricultural and Forest Meteorology*, *297*, 1. https://doi.org/10.1016/j.agrformet.2020.108245

Berendse, F., Van Ruijven, J., Jongejans, E., Keesstra, S.D. (2015). Loss of plant species diversity reduces soil erosion resistance of embankments that are crucial for the safety of human societies in low-lying areas. *Ecosystems*, *18*(5), 881-888. https://doi.org/10.1007/s10021-015-9869-6

Berila, A., Dushi, M. (2021). Measuring Surface Urban Heat Island in response to population density based on Remote Sensing data and GIS techniques: Application to Prishtina, Kosovo. *Folia Geographica*, *63*(2), 38-57.

Berila, A., Isufi, F. (2021a). Two Decades (2000-2020) Measuring Urban Sprawl Using GIS, RS and Landscape Metrics: a Case Study of Municipality of Prishtina (Kosovo). *Journal of Ecological Engineering*, *22*(6), 114-125. https://doi.org/10.12911/22998993/137078

Berila, A., Isufi, F. (2021b). "Mapping summer SUHI and its impact on the environment using GIS and Remote Sensing techniques: A case study on Municipality of Prishtina (Kosovo)". *European Journal of Geography*, *12*(3), 113-129. https://doi.org/10.48088/ejg.a.ber.12.3.113.129

Berila, A., Isufi F. (2021c). Application of GIS in the determination of vertical relief fragmentation: A case study on Drenica river basin (Kosovo). *Geographia Technica*, *16*(1), 39-47. https://doi.org/10.21163/GT_2021.161.04

Berila, A., Isufi, F. (2021d). Determination of Dissection Index (DI) using GIS & RS techniques: A case study on drenica river basin. *Folia Geographica*, *63*(1), 5-18.

Bhuiyan, C., Saha, A.K., Bandyopadhyay, N., Kogan, F.N. (2017). Analyzing the impact of thermal stress on vegetation health and agricultural drought – a case study from Gujarat, India. *GIScience & Remote Sensing*, *54*(5), 678-699. https://doi.org/10.1080/15481603.2017.1309737

Bowler, D.E., Bjorkman, A.D., Dornelas, M., Myers-Smith, I. H., Navarro, L.M., Niamir, A., Supp, S.R., Waldock, C., Winter, M., Vellend, M., Blowes, SH.A., Böhning-Gaese, K., Bruelheide, H., Elahi, R., Antão, L.H., Hines, J., Isbell, F., Jones, H.P., Magurran, A.E., Cabral, J.S., Bates, A.E. (2020). Mapping human pressures on biodiversity across the planet uncovers anthropogenic threat complexes. *People and Nature*, *2*(2), 380-394. https://doi.org/10.1002/pan3.10071

Buizer, M., Humphreys, D., De Jong, W. (2014). Climate change and deforestation: The evolution of an intersecting policy domain. *Environmental Science & Policy*, *35*, 1-11. https://doi.org/10.1016/j.envsci.2013.06.001

Coomes, D.A., Flores, O., Holdaway, R., Jucker, T., Lines, E.R., Vanderwel, M.C. (2014). Wood production response to climate change will depend critically on forest composition and structure. *Global Change Biology*, *20*(12), 3632-3645. https://doi.org/10.1111/gcb.12622

Dashpurev, B., Wesche, K., Jäschke, Y., Oyundelgerk., Phan, T.N., Bendix, J., Lehnert, L.W. (2021). A cost-effective method to monitor vegetation changes in steppes ecosystems: A case study on remote sensing of fire and infrastructure effects in eastern Mongolia. *Ecological Indicators*, *132*, 1-22. https://doi.org/10.1016/j.ecolind.2021.10833

Dien, V. T. (2004). *Susceptibility to forest degradation: A case study of the application of remote sensing and GIS in Bach Ma National Park, Thua-Thien Hue Province, Vietnam* [Master's thesis, International Institution for Geo-Information and Earth Observation]. Enschede.

Dindaroglu, T., Babur, E., Yakupoglu, T., Rodrigo-Comino, J., Cerdà, A. (2021). Evaluation of geomorphometric characteristics and soil properties after a wildfire using Sentinel-2 MSI imagery for future fire-safe forest. *Fire Safety Journal*, *122*, 103318. https://doi.org/10.1016/j.firesaf.2021.103318

Dutta, D., Kundu, A., Patel, N.R., Saha, S.K., Siddiqui, A.R. (2015). Assessment of agricultural drought in Rajasthan (India) using remote sensing derived Vegetation Condition Index (VCI) and Standardized Precipitation Index (SPI). T*he Egyptian Journal of Remote Sensing and Space Science*, *18*(1), 53-63. https://doi.org/10.1016/j.ejrs.2015.03.006

El Kateb, H., Zhang, H., Zhang, P., Mosandl, R. (2013). Soil erosion and surface runoff on different vegetation covers and slope gradients: A field experiment in Southern Shaanxi Province, China. *CATENA*, *105*, 1-10. https://doi.org/10.1016/j.catena.2012.12.012

EnvironmentaL Protection Authority (EPA). (2012). *National Report of Ethiopia. United Nations Conference on Sustainable Development (Rio+20)*. Federal Democratic Republic of Ethiopia, Addis Ababa. Retrieved January 25, 2023, from: https://sustainabledevelopment.un.org/content/documents/973ethiopia.pdf

Evans, K., Murphy, L., De Jong, W. (2013). Global versus local narratives of REDD: a case study from Peru's Amazon. *Environmental Science and Policy*, *35*, 98-108. https://doi.org/10.1016/j.envsci.2012.12.013

Findlay, C.S., Bourdages, J. (2000). Response time of wetland biodiversity to road construction on adjacent lands. *Conservation Biology*, *14*(1), 86-94.

Fu, B., Liu, S., Ma, K., Zhu, Y. (2004). Relationships between soil characteristics, topography and plant diversity in a heterogeneous deciduous broad-leaved forest near Beijing, China. *Plant and Soil*, *261*(1), 47-54. https://doi.org/10.1023/B:PLSO.0000035567.97093.48

Ganaie, T.A., Jamal, S., Ahmad, W.S. (2021). Changing land use/land cover patterns and growing human population in Wular catchment of Kashmir Valley, India. *GeoJournal*, *86*(4), 1589-1606. https://doi.org/10.1007/s10708-020-10146-y

Gebrehiwetk, B. (2004). *Land use land cover changes in the central highlands of Ethiopia: The case of Yerer mountains and its surroundings.* [Master's thesis, Addis Ababa University]. Addis Ababa.

Gemitzi, A., Koutsias, N. (2021). Assessment of properties of vegetation phenology in fire-affected areas from 2000 to 2015 in the Peloponnese, Greece. *Remote Sensing Applications: Society and Environment*, *23*, 100535. https://doi.org/10.1016/j.rsase.2021.100535

Giroux, J.-F., Bergeron, Y., Veillette, J.J. (2001). Dynamics and morphology of giant circular patterns of low tree density in black spruce stands in northern Quebec. *Canadian Journal of Botany*, *79*(4), 420-428. https://doi.org/10.1139/b01-022

Gomes, A.C.C., Bernardo, N., Alcântara, E. (2017). Accessing the southeastern Brazil 2014 drought severity on the vegetation health by satellite image. *Journal of Natural Hazards*, *89*(3), 1401-1420. https://doi.org/10.1007/s11069-017-3029-6

Gonçalves, N. B., Lopes, A.P., Dalagnol, R., Wu, J., Pinho, D.M., Nelson, B.W. (2020). Both near-surface and satellite remote sensing confirm drought legacy effect on tropical forest leaf phenology after 2015/2016 ENSO drought. *Remote Sensing of Environment*, *237*, 111489. https://doi.org/10.1016/j.rse.2019.111489

Hanewinkel, M., Cullmann, D.A., Schelhaas, M.-J., Nabuurs, G.-J., Zimmermann, N.E. (2012). Climate change may cause severe loss in the economic value of European forest land. *Nature Climate Change*, *3*(3), 203-207. https://doi.org/10.1038/nclimate1687

Hanski, I. (2015). Habitat fragmentation and species richness. *Journal of Biogeography*, *42*(5), 989-993. https://doi.org/10.1111/jbi.12478

Hislop, S., Haywood, A., Jones, S., Soto-Berelov, M., Skidmore, A., Nguyen, T.H. A (2020). Satellite data driven approach to monitoring and reporting fire disturbance and recovery across boreal and temperate forests. *International Journal of Applied Earth Observation and Geoinformation*, *87*, 102034. https://doi.org/10.1016/j.jag.2019.102034

Hou, G., Bi, H., Huo, Y., Wei, X., Zhu, Y., Wang, X., Liao, W. (2020). Determining the optimal vegetation coverage for controlling soil erosion in Cynodon dactylon grassland in North China. *Journal of Cleaner Production*, *244*(4), 118771. https://doi.org/10.1016/j.jclepro.2019.118771

Huang, J., Van Den Dool, H.M., Georgakakos, K.P. (1996). Analysis of model-calculated soil moisture over the United States (1931–1999) and applications to longrange temperature forecasts. *Journal of Climate*, *9*(6), 1350-1362. https://doi.org/10.1175/1520-0442(1996)009<1350:AOMCSM>2.0.CO;2

Isufi, F., Berila, A. (2021). Using geospatial technology to analyse land use/cover changes in Prishtina, Kosovo (2000-2020). *GeoJournal*, *87*, 3639–3653. https://doi.org/10.1007/s10708-021-10452-z

Jin, F., Yang, W., Fu, J., Li, Z. (2021). Effects of vegetation and climate on the changes of soil erosion in the Loess Plateau of China. *Science of The Total Environment*, *773*(3235), 145514. https://doi.org/10.1016/j.scitotenv.2021.145514

Khosravi, H., Haydari, E., Shekoohizadegan, S., Zareie, S. (2017). Assessment the Effect of Drought on Vegetation in Desert Area using Landsat Data. *The Egyptian Journal of Remote Sensing and Space Science*, *20*, 3-12. https://doi.org/10.1016/j.ejrs.2016.11.007

Kosovo Agency of Statistics (KAS). (2024). *Population and housing census in Kosovo: Preliminary results*. Retrieved October 1, 2024, from https://askapi.rks-gov.net/Custom/1d268e37-5934-4bd5-bbd1-34a9965cff92.pdf

Kundu, A., Dwivedi, S., Dutta, D. (2016). Monitoring the vegetation health over India during contrasting monsoon years using satellite remote sensing indices. *Arabian Journal of Geosciences*, *9*(2), 144. https://doi.org/10.1007/s12517-015-2185-9

Lin, D., Xia, J., Wan, S. (2010). Climate warming and biomass accumulation of terrestrial plants: a meta-analysis. *New Phytologist*, *188*(1), 187-198. https://doi.org/10.1111/j.1469-8137.2010.03347.x

Lin, Y., Cui, P., Ge, Y., Chen, C., Wangd., Wu, C-Zh., Li, J., Yu, W., Zhang, G-Sh., Lin, H. (2014). The succession characteristics of soil erosion during different vegetation succession stages in dry-hot river valley of Jinsha River, upper reaches of Yangtze River. *Ecological Engineering*, *62*, 13-26. https://doi.org/10.1016/j.ecoleng.2013.10.020

Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzaloj., Sedl, R., Delzon, S., Corona, P., Kolström, M., Lexer, M.J., Marchetti, M. (2010). Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. *Forest Ecology and Management*, *259*(4), 698-709. https://doi.org/10.1016/j.foreco.2009.09.023

Luttrell, C., Resosudarmo, I.A.P., Muharrom, E., Brockhaus, M., Seymour, F. (2014). The political context of REDD+ in Indonesia: Constituencies for change. *Environmental Science & Policy*, *35*, 67-75. https://doi.org/10.1016/j.envsci.2012.10.001

Matthews, T.J., Cottee-Jones, H.E., Whittaker, R.J. (2014). Habitat fragmentation and the species–area relationship: a focus on total species richness obscures the impact of habitat loss on habitat specialists. *Diversity and Distributions*, *20*(10), 1136-1146. https://doi.org/10.1111/ddi.12227

Maurya, P. K., Ali, S. A., Ahmad, A., Zhou, Q., Da Silva Castro, J., Khan, E., & Ali, H. (2020). An introduction to environmental degradation: Causes, consequences, and mitigation. In V. Kumar, J. Singh, & P. Kumar (Eds.), *Environmental degradation: Causes and remediation strategies* (1st ed., pp. 227). Agro Environ Media. https://doi.org/10.26832/aesa-2020-edcrs-01

Minale, A.S., Gelaye, S. (2021). Vegetation vulnerability analysis by using GIS and remote sensing techniques: a case study of Sensawuha Watershed, Ethiopia. *GeoJournal*, *86*(1), 475-488. https://doi.org/10.1007/s10708-019-10082-6

Moody, J.A., Martin, D.A. (2001). Post-fire, rainfall intensity-peak discharge relations for three mountainous watersheds in the western USA. *Hydrological Processes*, *15*(15), 2981-2993. https://doi.org/10.1002/hyp.386

Morgan, R. P. C. (1986). *Soil erosion and conservation* (3rd ed.). Longman.

Municipality of Prishtina. (2013). *Municipal development plan of Prishtina 2012–2022*. Retrieved January 22, 2023, from https://prishtinaonline.com/uploads/prishtina_pzhk_2012-2022_shqip%20(1).pdf

Nair, C. T. S., & Tieguhong, J. (2004). *African forests and forestry: An overview*. African Forest Forum: Nairobi, Kenya. Retrieved January 18, 2023, from https://afforum.org/oldaff/sites/default/files/English/English_36.pdf

Niu, J., Chen, J., Sun, L. (2015). Exploration of drought evolution using numerical simulations over the Xijiang (West River) basin in South China. *Journal of Hydrology*, *526*, 68-77. https://doi.org/10.1016/j.jhydrol.2014.11.029

North, H., Amies, A., Dymond, J., Belliss, S., Pairman, D., Drewry, J., Schindler, J., Shepherd, J. (2021). Mapping bare ground in New Zealand hill-country agriculture and forestry for soil erosion risk assessment: An automated satellite remote-sensing method. *Journal of Environmental Management*, *301*(4), 113812. https://doi.org/10.1016/j.jenvman.2021.113812

Novara, A., Pisciotta, A., Minacapilli, M., Maltese, A., Capodici, F., Cerdà, A., Gristina, L. (2018). The impact of soil erosion on soil fertility and vine vigor. A multidisciplinary approach based on field, laboratory and remote sensing approaches. *Science of The Total Environment*, *622-623*, 474-480. https://doi.org/10.1016/j.scitotenv.2017.11.272

Paterson, M., & Newell, P. (2010). *Climate capitalism: Global warming and the transformation of the global economy* (1st ed.). Cambridge University Press.

Pei, F., Wu, C., Liu, X., Li, X., Yang, K., Zhou, Y., Wang, K., Li, X., Xia, G. (2018). Monitoring the vegetation activity in China using vegetation health indices. *Agricultural and Forest Meteorology*, *248*, 215-227. https://doi.org/10.1016/j.agrformet.2017.10.001

Pfaff, A., Robalino, J., Walker, R., Aldrich, S., Caldas, M., Reis, E., Perz, S., Bohrer, C., Arima, E., Laurence, W., Kirby, K. (2007). Road investments, spatial spill overs, and deforestation in the Brazilian Amazon. *Journal of Regional Science*, *47*(1), 109-123. https://doi.org/10.1111/j.1467-9787.2007.00502.x

Richards, J. A. (1995). *Remote sensing digital image analysis: An introduction* (5th ed.). Springer.

Ripple, W.J., Smith, P., Haberl, H., Montzka, S.A., Mcalpine, C., Boucher, D.H. (2013). Ruminants, climate change and climate policy. *Nature Climate Change*, *4*(1), 2-5. https://doi.org/10.1038/nclimate2081

Saaty, R.W. (1987). The analytic hierarchy process—what it is and how it is used. *Mathematical Modelling*, *9*(3-5), 161-176. https://doi.org/10.1016/0270-0255(87)90473-8

Schröter, D., Cramer, W., Leemans, R., Prentice, I. C., Araújo, M. B., Arnell, N. W., Bondeau, A., Bugmann, H., Carter, T. R., Gracia, C. A., de la Vega-Leinert, A. C., Erhard, M., Ewert, F., Glendining, M., House, J. I., Kankaanpää, S., Klein, R. J. T., Lavorel, S., Lind-Ner, M., Metzger, M. J., Meyer, J., Mitchell, T. D., Reginster, I., Rounsevell, M., Sabaté, S., Sitch, S., Smith, B., Smith, J., Smith, P., Sykes, M. T., Thonicke,

K., Thuiller, W., Tuck, G., Zaehle, S., & Zierl, B. (2005). Ecosystem service supply and vulnerability to global change in Europe. *Science*, *310*(5752), 1333–1337. https://doi.org/10.1126/science.1115233

Shakesby, R.A., Doerr, S.H., Walsh, R.P.D. (2000). The erosional impact of soil hydrophobicity: current problems and future research directions. *Journal of Hydrology*, *231-232*, 178-191. https://doi.org/10.1016/S0022-1694(00)00193-1

Simard, M., Lecomte, N., Bergeron, Y., Bernier, P.Y., PARÉ, D. (2007). Forest productivity decline caused by successional paludification of boreal soils. *Ecological Applications*, *17*(6), 1619-1637. https://doi.org/10.1890/06-1795.1

Sun, C., Hou, H., Chen, W. (2021). Effects of vegetation cover and slope on soil erosion in the Eastern Chinese Loess Plateau under different rainfall regimes. *PeerJ*, *9*(3-4), 1. https://doi.org/10.7717/peerj.11226

Tsegaye, B. (2019). Effect of Land Use and Land Cover Changes on Soil Erosion in Ethiopia. *International Journal of Agricultural Science and Food Technology*, *5*(1), 26-34. http://doi.org/10.17352/2455-815X.000038

Tsymbarovich, P., Kust, G., Kumani, M., Golosov, V., Andreeva, O. (2020). Soil erosion: An important indicator for the assessment of land degradation neutrality in Russia. *International Soil and Water Conservation Research*, *8*(4), 418-429. https://doi.org/10.1016/j.iswcr.2020.06.002

Vieira, D.C.S., Malvar, M.C., Martins, M.A.S., Serpa, D., & Keizer, J.J. (2018). Key factors controlling the post-fire hydrological and erosive response at micro-plot scale in a recently burned Mediterranean forest. *Geomorphology*, *319*, 161-173. https://doi.org/10.1016/j.geomorph.2018.07.014

Wang, H., Stephenson, S.R. (2018). Quantifying the impacts of climate change and land use/cover change on runoff in the lower Connecticut River Basin. *Hydrological Processes*, *32*(9), 1301-1312. https://doi.org/10.1002/hyp.11509

Wang, Z., Jiao, J., Su, Y., Chen, Y. (2014). The efficiency of large-scale afforestation with fish-scale pits for revegetation and soil erosion control in the steppe zone on the hillgully Loess Plateau. *CATENA*, *115*, 159-167. https://doi.org/10.1016/j.catena.2013.11.012

Way, D.A., Oren, R. (2010). Differential responses to changes in growth temperature between trees from different functional groups and biomes: a review and synthesis of data. *Tree Physiology*, *30*(6), 669-688. https://doi.org/10.1093/treephys/tpq015

Wiens, J.J. (2011). The niche, biogeography and species interactions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366* (1576), 2336-2350. https://doi.org/10.1098/rstb.2011.0059

Wu, J., Ma, W., Li, G., Alhassan, A.-R.M., Wang, H., Chen, G. (2020). Vegetation degradation along water gradient leads to soil active organic carbon loss in Gahai wetland. *Ecological Engineering*, *145*, 105666. https://doi.org/10.1016/j.ecoleng.2019.105666

Yin, C., He, B., Quan, X., Yebra, M., Lai, G. (2020). Remote Sensing of Burn Severity Using Coupled Radiative Transfer Model: A Case Study on Chinese Qinyuan Pine Fires. *Remote Sensing*, *12*(21), 3590. https://doi.org/10.3390/rs12213590

Yu, Y., Jia, Z.Q. (2014). Changes in soil organic carbon and nitrogen capacities of Salix cheilophila Schneid along a revegetation chronosequence in semi-arid degraded sandy land of the Gonghe Basin, Tibet Plateau. *Solid Earth*, *5*(2), 1045-1054. https://doi.org/10.5194/se-5-1045-2014

Zhang, L., Jiao, W., Zhang, H., Huang, C., Tong, Q. (2017). Studying drought phenomena in the Continental United States in 2011 and 2012 using various drought indices. *Remote Sensing of Environment*, *190*, 96-106. https://doi.org/10.1016/j.rse.2016.12.010

Zhu, K., Woodall, C.W., Ghosh, S., Gelfand, A.E., Clark, J.S. (2013). Dual impacts of climate change: forest migration and turnover through life history. *Global Change Biology*, *20*(1), 251-264. https://doi.org/10.1111/gcb.12382